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(54) Title: PROCEDURE FOR CONTROLLING IC ENGINES

(57) Abstract: A control assembly is described in relation to the control of a non linear system by a linearly controlled arrangement. In particular an event based control system is employed to overcome the problem of non linear torque control in spark ignition internal combustion engines. In addition to the torque control a means for controlling the engine efficiency is also described. Control of engine efficiency results in improved engine response to load disturbances when the engine is in the idle condition. The facility to vary the efficiency of an engine is also beneficial in situations where the thermal output of the engine is desired to be increased. Typically these occur after start up when it can be desirable to quickly heat up the vehicles catalyst or passenger compartment. The employment of a linear control system also leads to significantly reduced calibration times in the development stage of the engine.

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1 Procedure for controlling IC engines

2

3 This invention relates to the provision of a means of
4 providing linear control of a non-linear system. In
5 particular it relates to the provision of a system and
6 method for removing the non-linear nature of the torque
7 control problem in spark ignition internal combustion
8 (gasoline) engines and for allowing the control of engine
9 efficiency as well as torque. More specifically there is
10 described a method of using a set of signal manipulation
11 techniques at the (signal) input and output of the
12 gasoline engine that allows the use of standard linear
13 control techniques to accurately control both engine
14 torque and efficiency (or, equivalently, torque reserve).

15

16

17 Technical Background:

18 Traditionally, the torque output of a spark ignition
19 gasoline engine has been controlled directly by the
20 driver moving the throttle in the air intake path,
21 allowing more or less air to be inducted into the

1 cylinder with each induction stroke. The function of the
2 carburettor or fuel injection system being to add fuel to
3 the air such that the in-cylinder combination has a fixed
4 mass ratio. The spark timing would be controlled
5 (mechanically or electronically) with the goal of
6 obtaining the maximum torque possible from each
7 combustion event.

8

9 More recently, it has become commonplace to move the
10 spark timing away from that which gives the optimal
11 torque production in certain engine operating modes. Most
12 particularly the idle mode, a more complete discussion of
13 this application is given further in this document. In
14 order for the operating efficiency to be reduced whilst
15 still producing the same overall net torque from the
16 engine, the airflow into the engine must be increased.
17 For the engine controller to do this there must either be
18 an electronically controlled parallel airpath into the
19 engine or an electronically controlled main airpath into
20 the engine. Prior art techniques, whilst explaining the
21 various advantages of this reduction in efficiency, have
22 not explained explicitly how to achieve this seamlessly
23 in practice. Practical realisation of the reduction in
24 efficiency is straightforward to achieve if the desired
25 change in efficiency is slowly changing and the engine is
26 at one operating point, however if the desired change is
27 quickly varying or if the operating point of the engine
28 is rapidly changing then prior art methods are very
29 difficult to implement because of the nonlinear nature of
30 the engine system. This is the case for the three
31 examples given in this document, the techniques described
32 herein enabling greatly improved control in these cases.
33 The following section expands on the particular

1 requirements and difficulties of the idle control
2 problem.

3

4 The control of the speed of gasoline engines when
5 operating in the idle condition whilst keeping the rate
6 of fuel usage of the engine as low as possible presents a
7 number of difficulties. The speed of a gasoline engine at
8 idle is affected by many forms of disturbance; cyclic
9 variability in torque production, varying friction
10 characteristics of the engine and mechanical loads from
11 accessories such as the alternator, power steering pump
12 and air conditioning pump. The magnitude of the accessory
13 disturbances in particular has increased as the level of
14 standard equipment in vehicles increases. Thus on a cold
15 morning a driver may enter his/her car, start the engine,
16 and with the engine in idle condition, switch on the
17 front and rear electrical demisters, move the electric
18 chair to a more suitable condition, turn on the electric
19 chair heater and then make several lock-to-lock steering
20 movements to get out of the parking spot. The power
21 demand of the steering is at its highest when the vehicle
22 is stationary. All of the energy drains must be countered
23 by an increase in torque from the engine but without
24 perceivable changes in idle speed. To reject the effect
25 on speed of these disturbances, modern engines use
26 electronic engine control units and feedback control
27 techniques to keep the speed constant. Whilst in idle
28 mode, the airflow into the engine is controlled by the
29 engine management system using a secondary throttle,
30 (also known as an idle speed control valve (ISC) or air
31 bypass valve (ABV)) in parallel with the primary, driver
32 controlled throttle, or an electronically controlled main
33 throttle. Because the speed of response of this actuator
34 is slow (due to the time for the effect of the change in

1 secondary throttle, or electronic main throttle, position
2 to propagate through the manifold and affect the air
3 inducted into the cylinder), the spark timing is also
4 used. It being retarded from the point of optimal torque
5 production to a point that allows some torque reserve
6 which can be available for almost instant rejection of
7 torque disturbances. The further away from the timing for
8 optimal torque production that the engine is operated at,
9 the more torque reserve the engine/controller has but the
10 more fuel is used to keep the engine at the desired
11 speed. Methods for controlling the speed use a
12 measurement of speed and control the secondary throttle
13 or electronic main throttle, and spark timing. The
14 effectiveness of the idle control mechanism will dictate
15 the idle speed set point of the engine. A poor controller
16 will have to have a high idle set point so that low side
17 excursions do not cause the engine to stall. A figure
18 used by the industry is that every 100rpm decrease in
19 idle speed setpoint is approximately equivalent to one
20 mile per gallon improvement in fuel economy. Note again
21 that a poor idle controller will have to operate far from
22 optimal spark timing to achieve the torque reserve
23 necessary for stable idle. This alone can increase the
24 fuel used during idle by a factor of 2 or 3. Clearly an
25 effective controller which can operate close to optimal
26 spark timing and at a lower speed will make significant
27 fuel economy improvements.

28

29 Prior art techniques have traditionally relied on simple
30 linear controllers (typically of the proportional +
31 integral type) to control the spark and bypass valve in
32 response to a speed variation. These controllers have to
33 be calibrated at many different operating points so that
34 although the controller structure is simple, the

1 parameters that the controller uses will be based on
2 large look-up tables and the control action will have
3 many special case responses which again are the result of
4 many man months of calibration effort. The reason for the
5 inadequacy of this linear technique is that the system
6 itself is very non-linear. If the speed of the engine
7 drops as a result of an unanticipated load, then the
8 effect of the next spark will be different because we are
9 now at a different operating point, less torque will be
10 generated and thus the size of the excursion will
11 increase. Many researchers have tried more complicated
12 linear control techniques which have the advantage that
13 they may overcome some of the effects of the nonlinearity
14 and the disadvantage that they are generally
15 significantly harder to calibrate for the areas where a
16 variation in controller parameter is necessary.
17 Conversely, some non-linear techniques are available
18 which will enable the control engineer to take account of
19 some or all of the non-linear characteristics of the
20 engine when designing the controller. However these non-
21 linear techniques are very cumbersome in the design stage
22 so that designing a controller is possible but designing
23 a good controller is very difficult.

24

25 In a more general form the technique for making linear
26 the control of torque and operating efficiency
27 (equivalently, torque reserve) could be used in other
28 engine operating modes. Two examples are:

29

30 1) in the transition from homogeneous to stratified
31 charge mode in direct injection gasoline engines it
32 will be desirable to increase the manifold pressure
33 before the switch without increasing the torque. This
34 can be done by reducing the efficiency of the

1 combustion which is easily effected using this
2 technique

3

4 2) When preparing for the deactivation of one or more
5 cylinders in more general engine types it is desirable
6 to increase the torque reserve so that when the one or
7 more cylinders is/are deactivated, the remaining
8 active cylinders can rapidly increase their torque to
9 keep the overall torque output of the engine at the
10 desired level. This functionality is easily achievable
11 using the technique presented here.

12

13 In both of these examples the required change in
14 efficiency is rapid, existing techniques being very
15 difficult to implement successfully in these cases.

16

17 It is an object of the present invention to provide a
18 control system and method that allows the use of standard
19 linear control techniques to control an essentially non-
20 linear system such as a gasoline engine.

21

22 It is a further object of the present invention to
23 improve a gasoline engine's response to load disturbances
24 in the idle condition.

25

26 It is a still further object of the invention to provide
27 a means of varying the operating efficiency of a gasoline
28 engine in order to increase the thermal energy output of
29 the engine in specified circumstances.

30

31 It is a still further object of the present invention to
32 provide a control system and method which requires
33 significantly less calibration time in the development
34 stage than prior techniques.

1

2 According to the present invention there is provided a
3 control assembly for a non linear system comprising non-
4 linear map interface means connecting input and output
5 points of the non linear system to a linear control
6 arrangement.

7

8 The non-linear system may, for example, be a spark
9 ignition gasoline engine.

10

11 The control assembly may be the idle speed control system
12 or engine management system of the gasoline engine.

13

14 Controlled inputs to the engine are preferably spark
15 timing and secondary throttle, or electronic main
16 throttle, settings and measured engine outputs include
17 engine speed and manifold pressure.

18

19 Further according to the present invention there is
20 provided an internal combustion engine management system
21 which provides control of engine input parameters in
22 accordance with an anticipated load disturbance resulting
23 from the operation of engine auxiliary components in
24 advance of the application of the said load.

25

26 Preferably, but not necessarily, the engine management
27 system controls both the engine input parameters and the
28 load disturbing components such that engine output torque
29 may be increased in accordance with increased load
30 application.

31

32 Still further according to the present invention there is
33 provided an internal combustion engine management system
34 arranged for allowing the operation of the engine at

1 close to optimal efficiency in the idle condition, the
2 system being further arranged so as to decrease the
3 operating efficiency of the engine and increase the
4 thermal output of the engine in predetermined conditions.

5

6 Increased thermal output may be required in a cold start
7 situation where it is desirable to achieve normal
8 operating temperature as quickly as possible.

9

10 Alternatively, increased thermal output may be required
11 in a cold start situation to allow the catalyst to reach
12 operating temperature as quickly as possible.

13

14 Alternatively increased thermal output may be required in
15 order to maximise the heat output of an associated
16 heating system.

17

18 Embodiments of the present invention will now be
19 described by way of example with reference to the
20 accompanying drawings:

21

22 Figure 0 is a general representation of a method for
23 enclosing a non-linear engine system using the
24 method described herein to produce a resulting
25 system which is linear or almost linear from input
26 to output;

27 Figure 1a is a diagram illustrating the effect of
28 spark timing or torque production for a given engine
29 speed and manifold pressure (or, equivalently, air
30 flow);

31 Figure 1b is a diagram illustrating the map for
32 spark advance required to give desired torque
33 production for a given engine speed and manifold
34 pressure (or, equivalently, air flow);

1 Figure 2a is a representation of the effect of the
2 secondary throttle position on the manifold air
3 pressure and thence the distance from peak torque
4 (at any operating point); and

5 Figure 2b is a representation illustrating the use
6 of the inverse map for representing the non-linear
7 part of the manifold dynamics, such that the second
8 input-output pair also becomes a linear system (at
9 any operating point).

10

11 Disclosure of the invention:

12 The present invention overcomes the shortcomings
13 described above of prior art methods by utilising a
14 control scheme that includes signal manipulation
15 techniques to make a more easily controllable system. The
16 method, as illustrated in Figure 0, creates an overall
17 system which is not only linear, or almost linear,
18 (depending on implementation) from (new) inputs to
19 outputs, but also creates another synthetic output which
20 allows the direct on-line control of the efficiency, or
21 equivalently torque reserve, of the engine. Thus by
22 'wrapping' the engine using the method described, the
23 engine will appear linear, or almost linear, and
24 intuitive at all operating points likely to be met in the
25 idle regime. This has the advantage of allowing advanced
26 linear control techniques to be used, which can extract
27 more performance from the controller for less calibration
28 time. The nature of the interfacing method is such that
29 the parameters which characterise it can be identified
30 from a small number of test operations taking, compared
31 to prior art techniques, a vastly reduced amount of
32 testing time. The second output (MBT-T) being a measure
33 of efficiency of the engine allows the engineer to design
34 controllers which will allow very efficient operation

1 when few disturbances are anticipated, and quickly move
2 to a less efficient point when load disturbances are
3 imminent. Alternatively it enables smooth transitions
4 between engine operating modes by matching the torque
5 production either side of the transition.

6

7 More specifically, the torque produced by the combustion
8 event of a S.I. engine (assuming constant air-fuel ratio)
9 is a static function of the amount of charge in the
10 cylinder, the engine speed (spd) and the spark timing, or
11 equivalently, the manifold pressure (MAP) at the end of
12 the induction stroke, the engine speed and the spark
13 timing. This is illustrated in figure 1a. If the spark is
14 not allowed to go beyond the point of optimal torque then
15 the torque map can be inverted as suggested in figure 1b.
16 This inversion allows the engine management system to
17 control the torque production from the combustion event
18 directly, the relationship between torque and speed being
19 a linear one so the control design problem is
20 significantly easier.

21

22 More specifically, the spark timing, in conjunction with
23 a measurement of the manifold pressure at the end (or
24 some other portion) of the induction stroke of the
25 cylinder for which the next combustion event occurs, and
26 an estimate of the engine speed when the combustion event
27 occurs, can be set based on an inversion of the static
28 map, to give any desired combustion torque (T_{com}) over
29 the next combustion event within the limits of the map.

30

31 In this new system, the use of the second input (ssMAP)
32 is effectively to control the amount of torque reserve of
33 the engine, the first input can immediately demand a
34 torque increase and it will achieve it (within the

1 limitations imposed by the static map), however the
2 second input must always be operating such that the
3 engine has the required amount of spare torque capacity
4 available. The distance, MBT-T (in units of torque) that
5 the engine is operating from its peak torque production
6 is again a static function of the engine speed, the spark
7 timing and the manifold pressure, or equivalently the
8 engine speed, the manifold pressure and the combustion
9 torque. I.e. $MBT-T = f(\text{speed}, T_{\text{comb}}, \text{MAP})$. This static
10 relationship may be linear in the variables or if not
11 will be smooth enough to allow linearisation for design
12 purposes. Note that since this path is not critical to
13 the cycle by cycle behaviour of the system, the effect of
14 any linearisation errors will be small. The manifold
15 pressure itself behaves in a non-linear dynamic way
16 affected by the secondary throttle, or electronic main
17 throttle, and the engine speed. This non-linear dynamic
18 behaviour can be separated into a linear dynamic portion
19 (when measured in the discrete, event based domain) and a
20 non-linear static map, the relationship between the
21 secondary throttle position and the distance from peak
22 torque being illustrated in figure 2a. The non-linear
23 static map can again be inverted and when the inversion
24 is used, the second output is now a linear function of
25 the second input (termed ss_MAP here), and the first
26 input and output. This is illustrated in figure 2b.

27

28 Detailed description of the preferred embodiments.

29

30 Since the combustion process is itself an inherently
31 event based process, the natural framework for a high
32 performance idle speed controller is in the (combustion)
33 event based discrete time domain. The following describes

1 the engine model formed as a result of the use of the
2 method described.

3 1) Since the combustion torque is a function of the spark
4 (which is set at least one control event prior to the
5 combustion event) and the manifold air pressure at the
6 end of the induction stroke, delays must be applied to
7 each input. For a four-stroke, four cylinder engine,
8 the manifold pressure delay is one unit.

9 2) The manifold pressure dynamics can be assumed to be
10 first order with fixed coefficient (although this
11 method would also include higher order models)

12 3) The engine speed then follows from simple Newtonian
13 mechanics.

14 4) The second output is a linear combination of the
15 delayed (desired) combustion torque, the delayed
16 manifold pressure and the speed.

17

18 The model for a four-stroke, four cylinder engine will
19 thus typically have four states, the delayed Tcomb, the
20 delayed ss_MAP, the manifold pressure and the engine
21 speed. The technology described here can also be used to
22 control engines with more or less cylinders, and with
23 faster or slower sampling rates by changing the model in
24 a way which will be clear to experienced practitioners.
25 The model description given above does not preclude the
26 use of the method described in a continuous time based
27 design.

28

29 When the controller so designed using the modified engine
30 system as described above is implemented, it would be
31 usual, although not necessary, to substitute more
32 accurate estimations of the torque map and actual
33 readings of the manifold pressure to calculate the second
34 output.

1
2 The values in the non-linear maps can be obtained by
3 operating the engine in steady state at various operating
4 points and measuring the torque produced at that point.
5 For the secondary throttle, or electronic main throttle,
6 to manifold pressure relationship, the secondary
7 throttle, or electronic main throttle, can be opened in
8 step increments and the behaviour of the manifold
9 pressure recorded. Regression curves, look-up-tables or
10 other mapping techniques can be used to perform the non-
11 linear mappings.

12

13 The use of this method facilitates the use of several
14 other techniques with an ease that was not available with
15 prior art techniques. These include:

- 16 1) The use of feedforward torque estimates for known load
17 disturbances. Since the input to the augmented system
18 is combustion torque, if the load torque of a
19 disturbance can be estimated, it can be cancelled by
20 simply adding this estimate to the first system input.
21 This eliminates the response time inherent in feedback
22 systems and allows a potentially significant
23 improvement in controller performance.
- 24
- 25 2) If the load disturbance can be delayed by a small
26 amount (e.g. the air-conditioning is under the control
27 of the engine management system and can easily be
28 delayed by say 0.5 seconds before the pump is engaged)
29 then the torque reserve of the engine can be quickly
30 increased by changing the reference on the second
31 input. Then when the load is engaged there is a lot of
32 reserve torque available to reject the disturbance.
33 Soon (e.g. 0.5seconds or less) after the load has been
34 engaged the operating point can be moved back to a more

1 fuel efficient one. Items 1) and 2) can of course be
2 utilised together to get the benefits of both.

3

4 3) Sometimes it is desirable to spend time with the engine
5 efficiency decreased significantly from optimal, by the
6 nature of the method described above, this is trivially
7 easy to achieve. When the efficiency is reduced, the
8 'wasted' energy becomes thermal energy this may be
9 desired for other purposes. Two examples of this are

10 i) After the engine has been started from cold it is
11 desirable to heat the catalytic converter up to
12 its normal operating temperature as quickly as
13 possible. By reducing the efficiency of the
14 engine, there is more thermal energy in the
15 exhaust gas that is transferred in part to the
16 catalytic converter.

17 ii) When idling in cold climates, the energy being
18 transferred to the engine block may not be
19 sufficient to keep the heater matrix hot enough to
20 keep the passenger compartment comfortable.
21 Reducing the efficiency of the engine increases
22 the amount of thermal energy transferred to the
23 engine block and hence the heater matrix.

24 iii) When starting from cold, it may be desirable to
25 transfer thermal energy rapidly to the engine
26 block in order to quickly reach normal operating
27 temperatures and to enable rapid heating of the
28 heater matrix, facilitating fast warm-up of the
29 passenger compartment and defrosting/demisting
30 system.

31

32 It will be appreciated that the ability of the system to
33 compensate for a wide range of potential load
34 disturbances allows the running of the engine far closer

1 to optimal conditions for more of the time than with
2 previous techniques. At the same time sub-optimal
3 operation is also possible where there is a requirement
4 to do so.

5

6 Modifications and improvements may be made without
7 departing from the scope of the present invention.

1 Claims

2

3 1. A control assembly for a non-linear system
4 comprising a non-linear map interface means that
5 connects input and output points of a non-linear
6 system to a linear control arrangement.

7

8 2. A control assembly as claimed in Claim 1 wherein the
9 non-linear system is a spark ignition gasoline
10 engine.

11

12 3. A control assembly as claimed in Claim 2 comprising
13 an idle speed control system or an engine management
14 system of the gasoline engine.

15

16 4. A control assembly as claimed in Claim 2 or 3
17 wherein the controlled inputs to the engine comprise
18 a spark timing and a secondary throttle, or an
19 electronic main throttle, and one or more settings
20 while the measured engine outputs comprise an engine
21 speed and a manifold pressure.

22

23 5. An internal combustion engine management system
24 comprising a provision for the control of engine
25 input parameters in accordance with an anticipated
26 load disturbance resulting from the operation of one
27 or more engine auxiliary components in advance of
28 the application of the said load.

29

30 6. An internal combustion engine management system as
31 claimed in Claim 5 wherein the engine management
32 system controls both the engine input parameters and
33 the load disturbing components such that an engine

1 output torque is increased in accordance with the
2 increased load application.

3

4 7. An internal combustion engine management system, for
5 allowing the operation of the engine at close to
6 optimal efficiency in the idle condition, wherein
7 the system is further configured so as to decrease
8 the operating efficiency of the engine and increase
9 the thermal output of the engine in pre-determined
10 conditions.

11

12 8. An internal combustion engine management system as
13 claimed in Claim 7 wherein the increased thermal
14 output is required in a cold start situation, where
15 it is desirable to achieve normal operating
16 temperature as quickly as possible.

17

18 9. An internal combustion engine management system as
19 claimed in Claim 7 wherein the increased thermal
20 output is required in a cold start situation, to
21 allow a catalyst to reach operating temperature as
22 quickly as possible.

23

24 10. An internal combustion engine management system as
25 claimed in Claim 7 wherein the increased thermal
26 output is required in order to maximise the heat
27 output of an associated heating system.

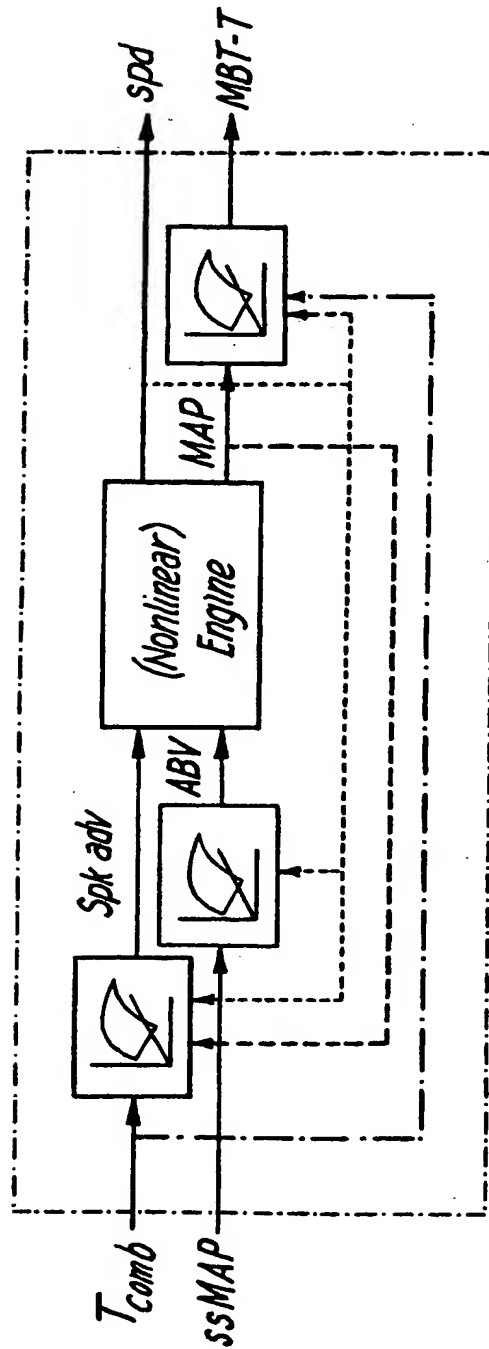


Fig. 1

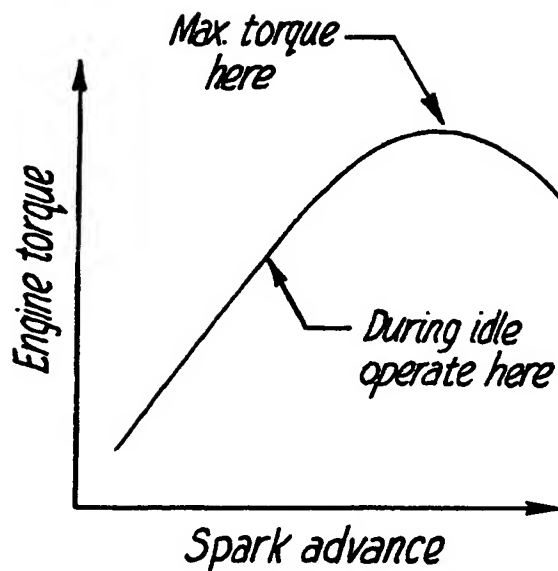


FIG. 1a

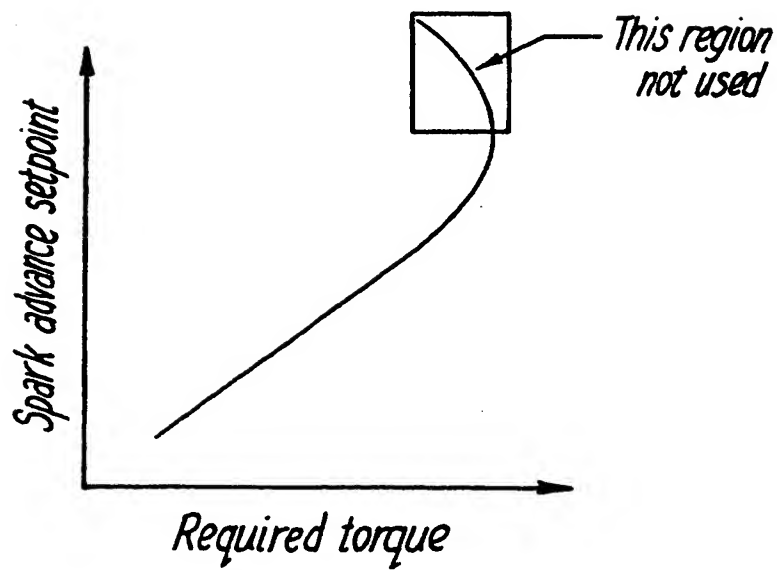
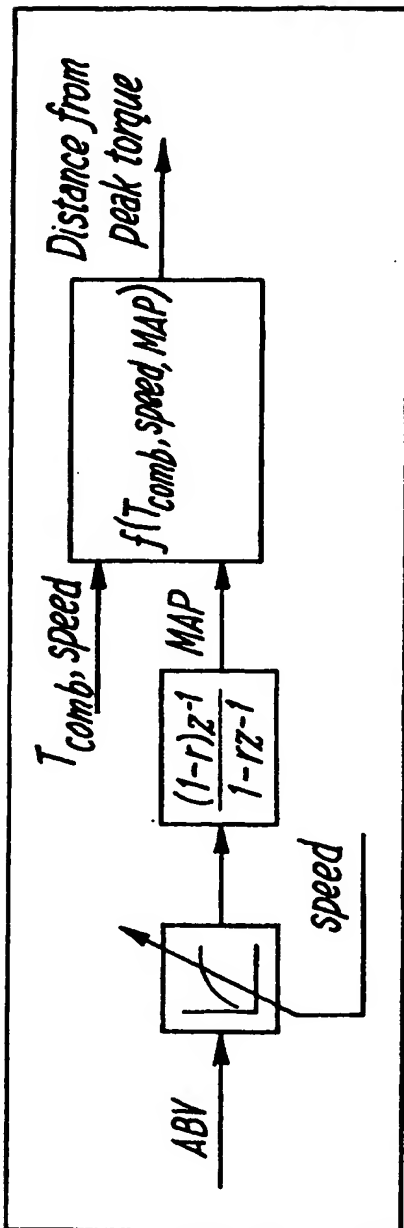
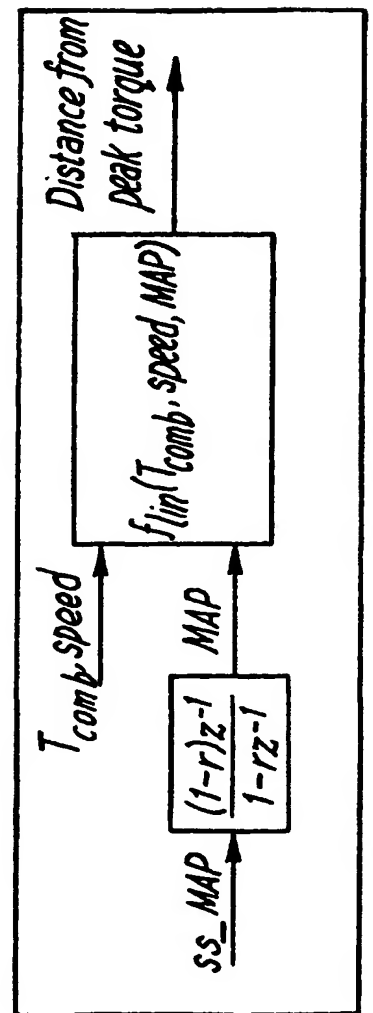
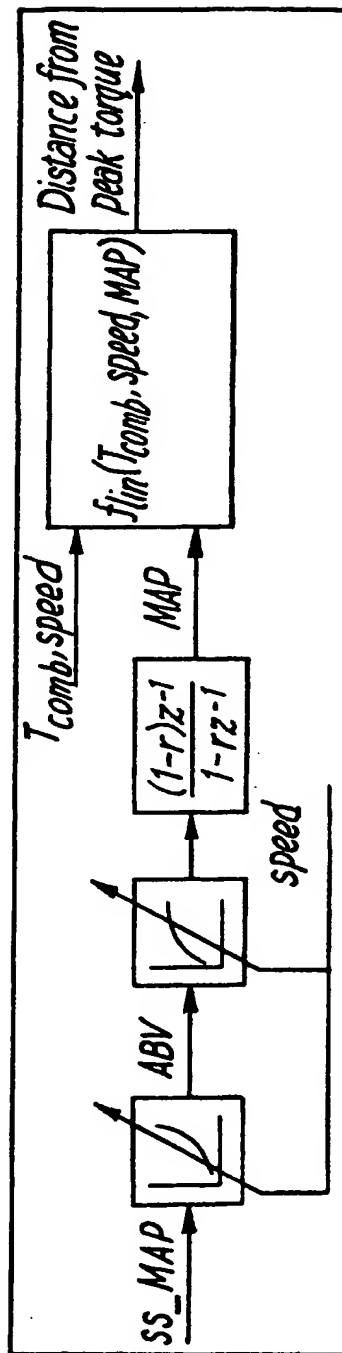


FIG. 1b

Fig. 2aFig. 2b

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For two-letter codes and other abbreviations, refer to the "Guid-
ance Notes on Codes and Abbreviations" appearing at the begin-
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(54) Title: **PROCEDURE FOR CONTROLLING IC ENGINES**

(57) Abstract: A control assembly is described in relation to the control of a non linear system by a linearly controlled arrangement. In particular an event based control system is employed to overcome the problem of non linear torque control in spark ignition internal combustion engines. In addition to the torque control a means for controlling the engine efficiency is also described. Control of engine efficiency results in improved engine response to load disturbances when the engine is in the idle condition. The facility to vary the efficiency of an engine is also beneficial in situations where the thermal output of the engine is desired to be increased. Typically these occur after start up when it can be desirable to quickly heat up the vehicles catalyst or passenger compartment. The employment of a linear control system also leads to significantly reduced calibration times in the development stage of the engine.

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INTERNATIONAL SEARCH REPORT

International Application No
PCT/GB 01/00677

A. CLASSIFICATION OF SUBJECT MATTER

IPC 7 F02D31/00 F02D37/02 F02D41/08 F02D41/06

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC 7 F02D

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, WPI Data, PAJ

C. DOCUMENTS CONSIDERED TO BE RELEVANT

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☒ Patent family members are listed in annex.

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Date of the actual completion of the international search

7 August 2001

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INTERNATIONAL SEARCH REPORT

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